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Imaging Complex Structures With Semi-recursive Kirchhoff Migration

by

Hesham Abdel Hamid Ebaid

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APPROVED, THESIS COMMITTEE:

William W. Symes, Chairman
Professor of Computational and Applied
Mathematics

Matthias Heinkenschloss,
Associate Professor of Computational and
Applied Mathematics

Alan Levander,
Chair and Carey Croneis Professor of
Geology and Geophysics

Houston, Texas
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ABSTRACT

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Attempting to image the subsurface in areas of complex geology and rapid lateral velocity variation is a challenging problem. In particular, using prestack Kirchhoff migration in conjunction with first arrival travel times produces poor subsurface images with increasing depth. This problem is not a limitation of Kirchhoff migration, but it is the failure of the finite difference method to compute travel times which correspond to the most energetic arrivals. Dimitri Bevc in1997 proposed a technique that combines the use of the wave equation datuming with dividing the velocity model into subsets. In each subset, calculation of the travel times with the finite differencing eikonal equation is valid. This thesis applies Bevc's technique using a software package (ProMAX) that is widely used among the academic and the industrial communities. We not only get a superior image at depth but we also enjoy the simplicity and the computational efficiency of using the finite difference method. We use the *Marmousi* synthetic dataset as input, which satisfies the definitions of structural complexity and rapid lateral velocity variation. To demonstrate the effectiveness of our approach, tests were performed on the M*armsoui* dataset before and after the application of the semi-recursive Kirchhoff migration.

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I would like to dedicate my thesis to my parents, my brothers and my sister, who always supported me through my life. Most of all, I thank my wife, Hanan, and my son, Omar, who have been and always will be the source of my joy and happiness.

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Chapter 1

Introduction

This thesis shows a technique that we can apply using commercial software and gets a superior subsurface image using Kirchhoff migration in conjunction with first arrival travel times. Searching for oil and gas in a complicated geologic environment or deep in the Earth has become common practice for oil and gas exploration. Researchers during the last ten years have investigated the possibility of using Kirchhoff migration in conjunction with first arrival travel times for subsurface imaging in such areas. Kirchhoff migration is based on summation of amplitudes in (x,t) space along the diffraction curve that corresponds to Huygens secondary source at each point in the (x,z) space (Yilmaz 1987)(see Figure 3.5). In other words, it is a summation of all data samples sharing the same *image point*. Still the question remains, why Kirchhoff migration? The answer is twofold. First, it can handle irregular sampling of input data, and that is the case in 3-D seismic, which has become more and more the favored way of subsurface imaging. Second, Kirchhoff migration is unique in its ability to migrate input traces selectively onto a prespecified output volume, and this capability allows a target-oriented 3-D prestack migration to be performed hundreds of times faster than other competing methods (Gray and May 1994).

Arrival time is the total time of transit from source to the image point and back to the receiver. We call it a “first arrival” if it hits the reflector (image point) and comes back to the receiver along the shortest possible two-way path. Later arrival (or travel) times associated with the same image point also arise when other travel paths are taken (see Figure (3.3). There are many ways of computing travel timetables, but the finite difference method is favored for its simplicity and speed. Travel time tables are important to migration because they determine which sample is to be summed to the image point. The finite difference method computes only the first arrival travel time for the diffraction point following the shortest travel path and thus is inaccurate for later arrivals associated with the same point.

Geoltrain and Brac in 1993 identified two problems with this combination of finite difference travel time computation and Kirchhoff migration, namely, *irregularity* and *incompleteness*. Irregularity occurs in the form of discontinuities in the travel time gradient, which cause a migration artifact known as "smiles". Incompleteness occurs when energetic events are migrated with unrelated travel times of the faster first arrival, causing mispositioning in the final image, specifically at depths where multiple arrivals exist. Thus, first arrival travel times computed by the finite difference method cannot be used to sum all data samples to the same image point.

Dmitri Bevc in 1997 proposed a solution for these problems. First, he divided the geological structure vis-a-vis its corresponding velocity model into subsets and then calculated first arrival travel times where the finite differencing eikonal solver was valid. Second, by downward continuation, he redatumed to depth level z and then imaged his data from this level. Thus, his method is one of alternating between steps of datuming and imaging. However, all the work that Bevc has done uses custom codes, which are not generally available.

Our work is a continuation of what Bevc has done, but instead of using proprietary software we will be using a commercially available processing package with its existing software. We will pay close attention to the wave equation datuming technique and show data before and after the datuming process, so we can better understand the difference between the migration per se and what is called downward or upward continuation. We will show that we can redatum a velocity model to a deeper datum and still maintain flat Common Depth Point gathers, i.e. CDP gathers whose primary events are still moved out correctly with respect to zero offset. In other words, we can remove the effect of the shallow complicated overburden from the velocity field and to do so, we can use a simple imaging algorithm. Finally, we will prove that by using the semi-recursive Kirchhoff migration technique we get a much better focused image compared to standard Kirchhoff migration.

For this work we chose the ProMAX (Landmark Graphic Corporation) package as our data processing platform given its wide use among geophysicists and geologists. For the input data, we chose the Marmousi synthetic dataset because it is sufficiently complex to prove our method, and because its known velocity model gave us no reason to use velocity as an excuse for any challenge we faced. We started the exercise by migrating the Marmousi data, and indeed we got a good image in the shallow section as well as on both sides of the model. Then we downward continued the data to a depth of 1000 meters; then we matched the velocity to the same datum. The seismic was the input to the prestack Kirchhoff depth migration. We produced CDP gathers and subsequently stacked these gathers. This stack showed a much better focused image at the target zone (approximately 2500 meters) compared to the standard Kirchhoff migration.

This thesis is built up as follows. In the next chapter we lay out the background of the problem as well some solutions that were proposed during the last ten years. Chapter 3 contains the materials and methods including a detailed description of the Marmousi model and a detailed description of first arrival travel time, Kirchhoff migration and wave equation datuming. Chapter 4 presents the semi-recursive Kirchhoff migration method and its results on the Marmousi dataset. In chapter 5 we present a discussion and future work for this method. We present our conclusions in chapter 6. Finally we will have an appendix for all the processing flows we used on ProMAX.

Chapter 2

Background

Worldwide demand for oil makes imaging the Earth's subsurface a very active subject. In 1993 Geoltrain and Brac asked the question, can we image complex structures with first-arrival travel time? They experienced imaging difficulties (images not sharp and complex structures mispositioned) with Kirchhoff migration using first-arrival travel times (Audebert et al., 1997; Gray and May, 1993). Their proposed solutions were to either ray trace to find the most energetic arrivals, or to calculate dynamically correct multiple- arrival Green's functions.

In 1994 Gray and May suggested with their research that Kirchhoff algorithms using first-arrival travel times do a poor job of imaging complex structures. Even travel time methods that calculate multiple arrivals and most energetic arrivals along with estimates of amplitude and phase do not always result in satisfactory images (Bevc, 1997).

In 1994 Dave Nichols calculated (band limited) Green's functions in the frequency domain to calculate travel times for Kirchhoff migration. He also estimated both amplitude and phase. He showed that calculating travel times in the frequency domain gives much better results given that the travel times track the high-energy part of the wave field better (Nichols, 1994). Travel times are still not able to capture all the events that should be summed coherently to form the best image. This travel time calculation method is computationally complex and much more costly than first-arrival travel time computation methods.

In his 1997 *Geophysics* article, Dimitri Bevc presents the topic of imaging complex structure with semirecursive Kirchhoff migration. It is generally accepted that migration algorithms that use recursive wave field continuation to backwards propagate the received wave field produce the best images. Unfortunately, these methods often require regular spatial sampling and are computationally intensive. This is why nonrecursive methods based on the Kirchhoff integral are attractive, especially for 3-D prestack imaging objectives. Kirchhoff algorithms can accommodate irregular sampling easily, and they can be applied in a target-oriented fashion. Using first-arrival travel times is popular because they are computed efficiently, and they have the attractive property of filling the entire computational grid (Bevc, 1997).

Bevc's approach depends on breaking up the complicated velocity structure. To do this he calculates the travel times in a subset of the velocity model where a finite difference solver such as Eikonal equation is valid. In other words, it computes all arrivals, and these arrivals can be considered first arrivals when they are sufficiently close to the source, i.e. no later arrivals exist. His method has the advantage of using a simple first-arrival travel times algorithm, which adds an efficiency factor to the process. The data can be resynthesized at any subsurface datum by downward continuation with a Kirchhoff datuming algorithm. The semirecursive definition came as a result of the datuming depth step being much greater than the depth step used in phase shift or finite-difference shot-profile migrations. After calculating the travel times from the surface, he uses those travel times to migrate from the surface to depth z1, and then he downward continues the data to the same depth z1. Then he calculates the travel times from depth z1 and uses them to migrate and downward continue the data to z2 and so forth. The data he uses is a synthetic 2-D data set modeled after the Cuanza basin in Angola, West Africa known as the *Marmousi* model (see section 3.1). The structural style of the Marmousi Model is dominated by growth faults that arise from salt creep and cause the complicated velocity structure in the upper part of the model. The main imaging objective is the reservoir in the anticlinal structure below the salt. The synthetic data set consists of 240 shots with 96 traces each.

Bevc applied the semirecursive algorithms to the Marmousi data by downward continuing the data to 1500 meters in one datum step. His result was a definite improvement from standard Krichhoff migration. He went further and shortened the datuming step to 500 meters and indeed got a better-focused image. He then compared his result with the following migrations:

- <u>Shot-profile Migration:</u> Data quality is almost the same as semirecursive Kirchhoff migration. But Bevc points out that this method is expensive and requires regular and fine sampling of the recording surface, which makes it impractical for 3-D Data.
- <u>Kirchhoff migration using maximum energy travel time using paraxial ray tracing:</u> Data quality of the semirecursive Kirchhoff migration showed better imaging than

migration using paraxial ray tracing. Migration using paraxial ray tracing requires extensive smoothing of the slowness model to ensure stability of the ray tracing.

- <u>Band-limited Green's function to calculate travel times for Kirchhoff migration:</u> Data quality of the semirecursive Kirchhoff migration is better than migration using Green's function to calculate travel times. The Green's function method shows that calculating travel times in the frequency domain has an advantage in tracking the high-energy portion of the wave field. However, this method was unable to capture all the energy to be summed coherently to form a better image.

Bevc concludes that semirecursive Kirchhoff migration not only creates better images but also has advantages in the following areas:

- If a velocity model is divided, then the numbers of travel time calculations are significantly reduced. Also the space required for storage during travel time calculation is much smaller.
- Computations per trace are reduced after each depth step.
- Migration and datuming apertures can be reduced. That means we will cut costs and the amount of input data in memory.

Chapter 3

Materials and Methods

This chapter will explain in detail the materials and methods used throughout the course of this research. We will start with a full description of the Marmousi model, then explain the first arrival travel time and the Kirchhoff migration concepts. Finally we will explain the wave equation datuming technique.

3.1 Marmousi Model:

Background

In 1988, a complex 2D geological model was generated and from it a synthetic seismic data set was generated (P. Ricarte and R. Versteeg). The model and the data were designed specifically by the Institut Francais du Petrole (IFP). The model was named Marmousi. The model incorporates two key properties:

- based on real geology
- represented a complex structure such that the assumptions on which conventional seismic data processing rely should not hold (A.Bourgeois et al., 1990).

Geological description

The Mamousi model is based on a profile through the north Quenguela trough the Cuanza basin in Angola (see Figure (3.1)). The basin is an isopachous saliferous evaporitic series on top of clayey-marl rich in organic materials (Verrier and Branco 1972). The geologic model of the basin consists of:

- A deltaic sediment interval, thickening from west to east, deposited upon a saliferous evaporitic series. The eastern portion is more affected by continuous lateral salt creep, and normal growth faults are developed.
- Presaliferous folded carbonate platform deposits in which a structural hydrocarbon trap is expected.

The geological history consists of two phases:

- The first phase corresponds to continuous platform sedimentation of marls and carbonates. At the end of this sequence these deposits were slightly folded then eroded with the erosion surface being flat.
- The second phase began with the deposition of thick shale-sandy detrital sediments, whose face thickness was governed by a continuous lateral creep of salt resulting from the overburden pressure. Linked to this salt creep, which may locally cause complete disappearances of the salt, dipping growth faults developed and were active continuously during the deposition of the detrital series.

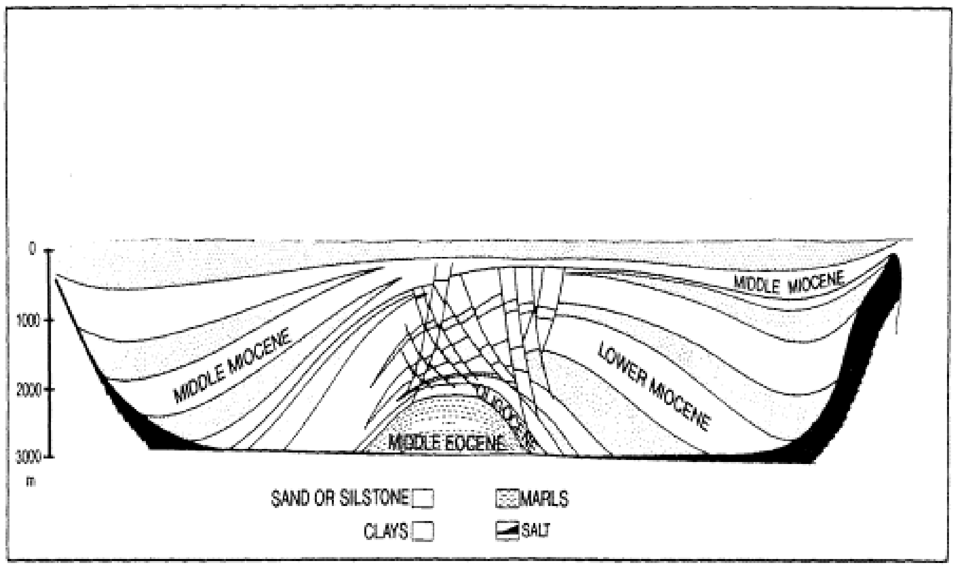


Figure 3.1 Profile of Cuansa Basin in Angola

Data acquisition

The line was shot from west to east. The first and last shot points were respectively located at 3000 and 8975 meters from the west edge of the model. The shot interval was 25 meters. The source consists of 6 waterguns with a spread of 40 meters; the shot point positions were in the middle of the source array. The watergun wavelet used for the modeling was obtaining by digitizing a real near field signature, which was filtered with a trapezoid frequency filter (0,10,40,60 Hz). The streamer was composed of 96 hydrophone groups. The group interval was 25 meters, near offset was 200 meters and a far offset was 2575 meters (see Figure (3.2)).

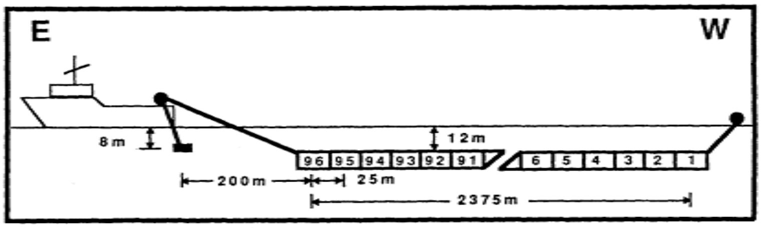


Figure 3.2 Streamer configuration

Data generation

The geometric model containing 160 layers was first generated using the MIMIC module of the SIERRA package. Then the velocity and density distributions were defined by introducing realistic horizontal and vertical velocity gradients. For the data generation, the modeling package performs the simulation of a whole seismic line across the geologic basin by computing successively the different shot records. This modeler uses a second order explicit finite-difference scheme. After the data generation a band pass filter (0,10,35,55 Hz) was used to partly remove the numerical dispersion.

3.2 First arrival travel times

Travel times in a homogeneous medium are all first arrivals where: T = d / v, T is time, d is depth and v is velocity. In the case of refraction, rays tend to bend towards slower velocity leading to multiple arrivals. Eikonal solvers use finite difference method to solve the eikonal equation. Eikonal equation computes only first arrival travel times (Vidale, 1988, van Trier and Symes, 1991).

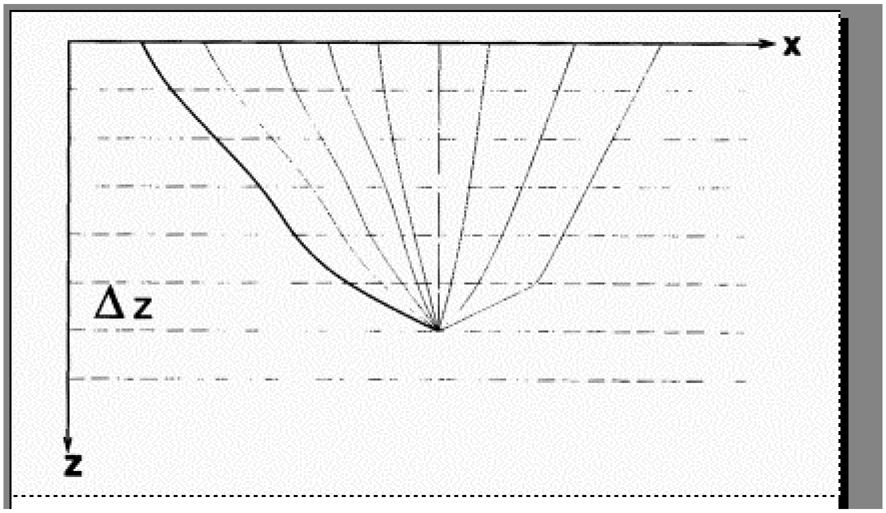


Figure 3.3 Propagation paths from the surface to an image point for Kirchhoff migration

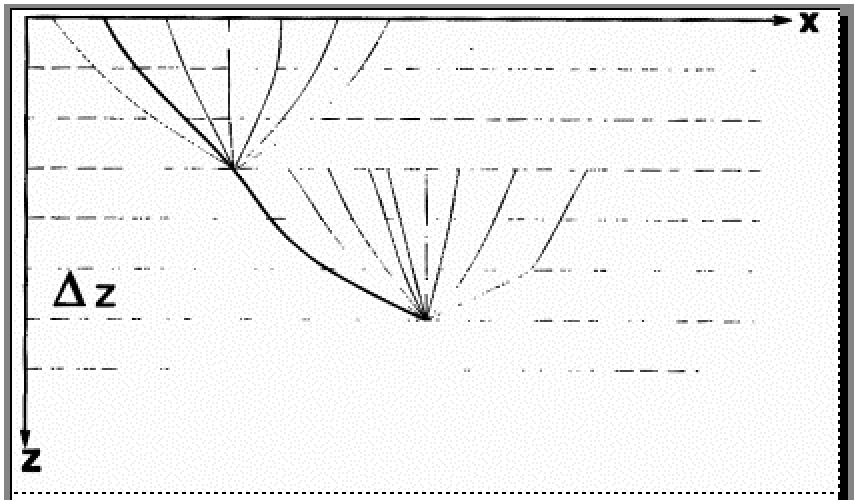


Figure 3.4 Propagation paths from the surface to an image point for the semi-recursive Kirchhoff migration

Gray and May in 1994 proposed an alternative to a previously employed approach of ray shooting (ray tracing) followed by interpolation of travel times onto a regular grid. They instead computed the travel times by directly solving the eikonal equation on a regular grid, without computing raypaths. Their new implementation of a gridded eikonal equation solver was designed to address the problem of interpolating time into the migration grid.

Bevc in his paper in Geophysics 1997 shows with a modeling program that the Marmousi velocity model generates complex propagation paths in which late energetic arrivals do not fit well with first arrival finite difference travel times. Figure 3.3 shows the propagation paths from the surface to an image point for Kirchhoff migration.
Figure 3.4 shows the propagation paths from the surface to an image point for Semi-recursive Kirchhoff migration. Bevc concludes that if the travel time calculation is limited to early times, the first arrival travel times accurately parameterize the most energetic portions of the acoustic wave field. The model he used generated snapshots of the acoustic wave field from two surface locations in the Marmousi model. This exercise is important because it explains the great improvement we achieved in the final image compared to the standard Kirchhoff migration.

3.3 Pre-stack Kirchhoff migration

1- Principles;

Migration moves dipping reflectors into their true subsurface positions and collapses diffraction, thereby delineating detailed subsurface features such as fault planes. Kirchhoff migration is based on summation of amplitudes of all times sharing the same image point. The migration scheme based on diffraction summation consists of searching the input data in (s,r,t) space for energy that would have resulted if a diffraction source were located at a particular point in the output (x,z) space(same as Kirchhoff migration). This search is carried out by summing the amplitudes in (s,r,t) space along the diffraction curve that corresponds to Huygens' secondary source at each point in the (x,z) space (see Figure 3.5). The result of this summation is then mapped onto the corresponding point in the (x,z) space. Diffraction summation is a straightforward summation of amplitudes along the hyperbolic trajectory whose curvature is governed by the velocity function (Yilmaz 1987). A key issue for Kirchhoff migration is the choice of an algorithm for generating travel time maps.

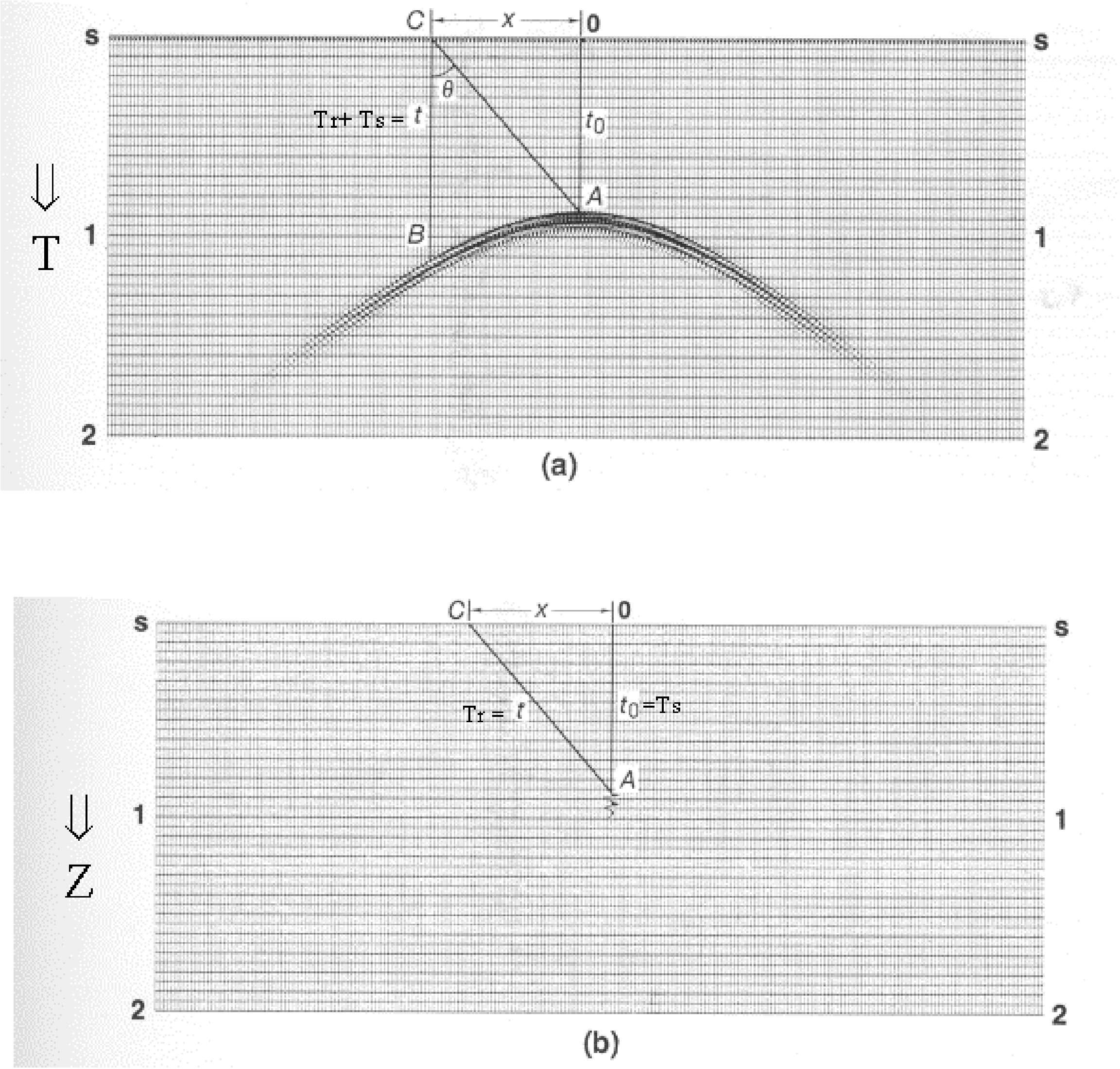


Figure 3.5 Amplitudes at input B in section (a) is summed along the diffraction curve and mapped into the output section (b) at location A. (Yilmaz, 1987)

2- Advantages:

- The Kirchhoff integral is attractive especially for pre-stack imaging objectives because it can accommodate irregular sampling easily. Irregular sampling is the case in 3-D seismic for both land and marine recordings.
- Kirchhoff migration is unique in its ability to migrate input traces selectively onto a target oriented output. This advantage allows 3-D prestack migration to be performed hundred of times faster by the Kirchhoff method than by competing methods such as shot profile and F-X migration.
- Kirchhoff migration works very efficiently when it uses first arrival travel times but mistimes and mispositions with later arrivals.

3.4 Pre-Stack Wave equation datuming:

Wave equation datuming is the name given to upward or downward continuation of seismic data when the purpose is to redefine the reference surface on which the sources and receivers appear to be located (Berryhill, 1979). This technique differs from conventional datuming methods because it is a dynamic rather than static approach. Wave equation datuming provides an alternative to velocity replacement static corrections, which assume that the layers can be stripped away and replaced vertically without regard to the changes in raypath angles caused by the implicit movement of sources and receivers to elevations different from where these were recorded. Performing this procedure on unstacked data requires no change in the mathematical algorithm. One must simply recognize that operating on common source traces has the effect of moving the receivers from one datum to another, and because of reciprocity, operating on common receiver traces likewise moves the datum of the sources. Two passes through the data, common source computations, then common receiver computations, are required to change the datum of an entire seismic line before stack from one surface to another (Berryhill, 1984). They are two approaches to the wave equation datuming:

- The Kirchhoff integral formulation of wave equation datuming can provide a basis for computation to deal with the irregular surfaces and variable velocities that are central to our problem. The numerical implementation of the Kirchhoff approach can be reduced to an efficient procedure involving summation and convolutions of seismic traces with short shaping and weighting operators (Berryhill 1979). This approach was not available in ProMAX, hence we did not use it.

- The other approach to wave equation datuming which, we used in this research performs upward or downward continuation of U (x, z = z1, t) to produce U (x, z = z2, t) using a finite difference extrapolators. A computer program designed to implement wave equation datuming must have some method of describing the input and output datums as curves in (x, z) space, together with some method for defining the wave propagation velocity in the medium bounded by the two datums.

Chapter 4

Semi-recursive Kichhoff Migration and Data Examples

This chapter will describe the work that we did with the Marmousi data on ProMAX. The first part will explain the data preparation. The second part is the standard Kirchhoff migration we performed on the Marmousi data. The third part is the wave equation datuming, which we did on the synthetic traces, Marmousi data and the velocity model. The last part will be the Kirchhoff migration of the redatumed data. All of that will be supported with data examples.

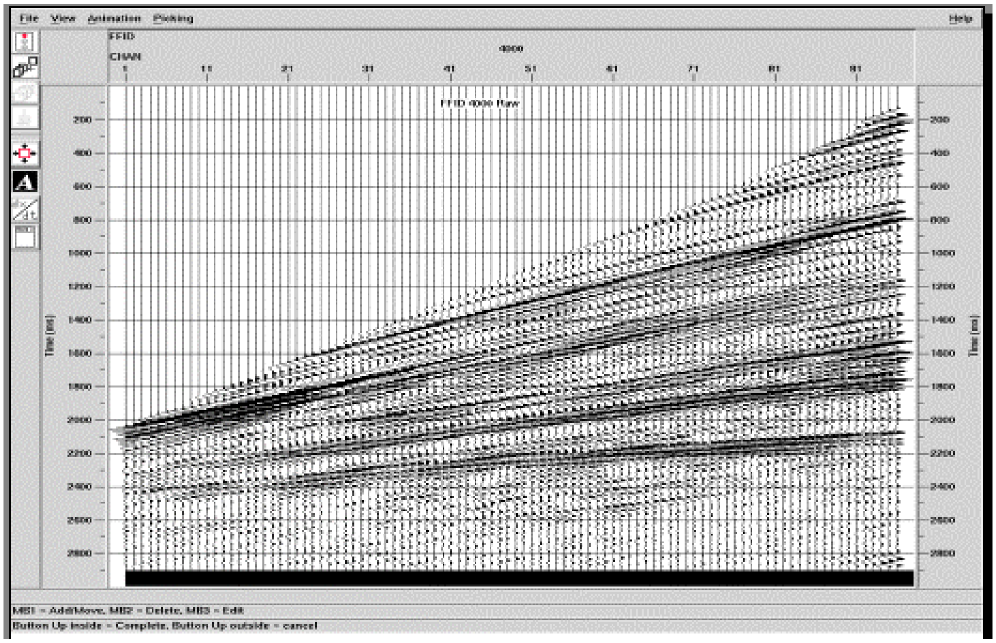
4.1 Data preparation:

Seismic:

The Marmousi data was transcribed from SEG-Y format (IEEE). A trace header dump was done to locate trace headers byte locations. The following headers were recovered:

FFID	byte 9
CHAN	byte 13
CDP	byte 21
SHT-X	byte 73
SHT-Y	byte 77
REC-X	byte 81
REC-Y	byte 85

A near trace stack was generated to check the coordinates as well as successful loading of the data on to ProMAX (Landmark processing package). The ProMAX is a widely used seismic processing package among geophysicists and geologists. Figure (4.1) shows FFID 4000 after the data were loaded on to ProMAX.



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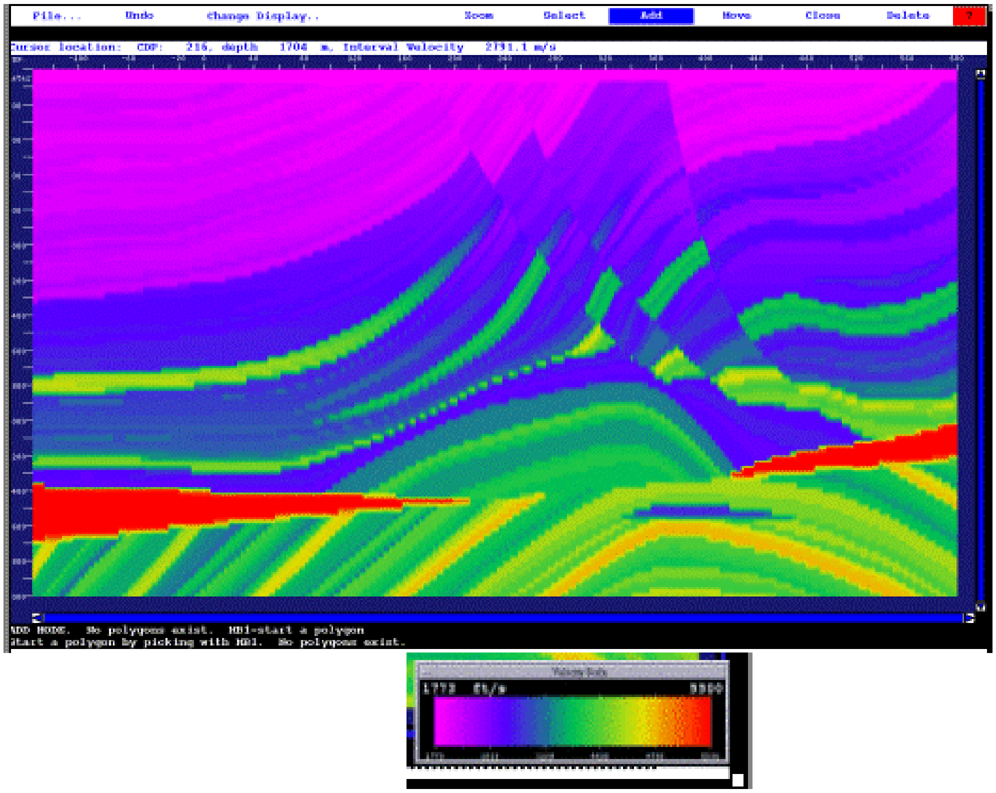
Button Up inside = Complete, Button Up outside = cancel

Figure 4.1 Marmosui synthetic data FFID 4000

Velocity:

The velocity model was transcribed from SEG-Y format (IEEE). After locating trace header byte locations, it appeared that the model was transposed. A processing flow was set up on ProMAX to rotate the model so it would match the seismic data. 2D geometry was loaded to the trace headers of the velocity model so CDP numbers would match the seismic data. Figure (4.2) shows the velocity model after the transposition. The colors correspond to velocity range of 1500 m. /sec. to 5500 m. /sec. The structure is dominated by growth faults that arise from salt creep and cause the complicated velocity structure in the shallow part of the model (Bevc, 1997). The objective is the reservoir in the anticline structure below salt where imaging technique using Kirchhoff migration in conjunction with first arrival travel times does not work (Geoltrain and Brac, 1993).



Cursor location: CDP: 216. depth 1704 m. Interval Velocity 2791.1 m/s

ADD MODE. No polygons exist. MB1=start a polygon
Start a polygon by picking with MB1. No polygons exist.

Figure 4.2 Marmousi velocity model

4.2 Pre-stack Kirchhoff migration of the Marmousi data

Before we run the data with the semi-recursive method, a standard Kirchhoff depth migration of the Marmousi data was needed to use as a comparison with the final image we get from the semi-recursive method. The Kirchhoff migration algorithm we used on PromMAX was the *Prestack Kirchhoff Depth Migration* (see appendix for the processing flow). It performs a migration by applying a Green's function to each CDP location using a travel time map. Travel times maps relate the time from each surface location to a region of points in the subsurface. This migration uses a vertically and laterally variant interval velocity field in depth, Vint (x,z). For travel time map computation we used *Implicit Eikonal Solver.*

After all of the Marmousi synthetic data were loaded, we set up a flow to perform a standard Kirchhoff migration using first arrival travel times calculated with the finite difference eikonal equation solver. The flow we used to perform the migration as follows:

Disk data input

Read the data sorted in FFID

Trace muting

Apply a ramp on mute to the first arrival

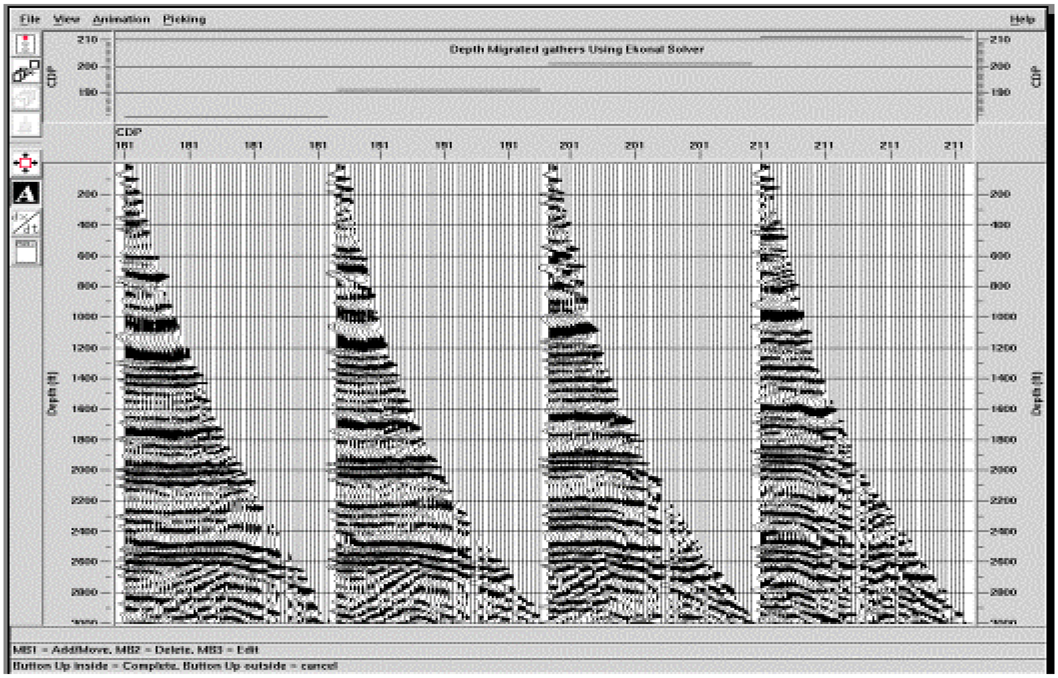
Prestack Kirchhoff migration

Finite difference eikonal equation solver

Disk data output

Output the data after migration.

The output of the migration is common image gathers; Figure (4.3) shows some of the migrated gathers. The gathers in the shallow section show a good flat event, but at a depth of around 2500 meters the section is not imaged very well and this is what we expected given the complexity of the model and using the first arrival travel times. These gathers were muted to clean up the wavelet stretching and then stacked.



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Button Up inside = Complete, Button Up outside = cancel

Figure 4.3 Depth migrated gathers

Fig (4.4) shows a stacked section for the whole Marmousi model. The stack shows well imaged faults in the shallow section as well as the beds on both sides of the model. However, the image at the target anticline zone is not well imaged.

Fig (4.5) shows the velocity model with the stack as a template in the background.

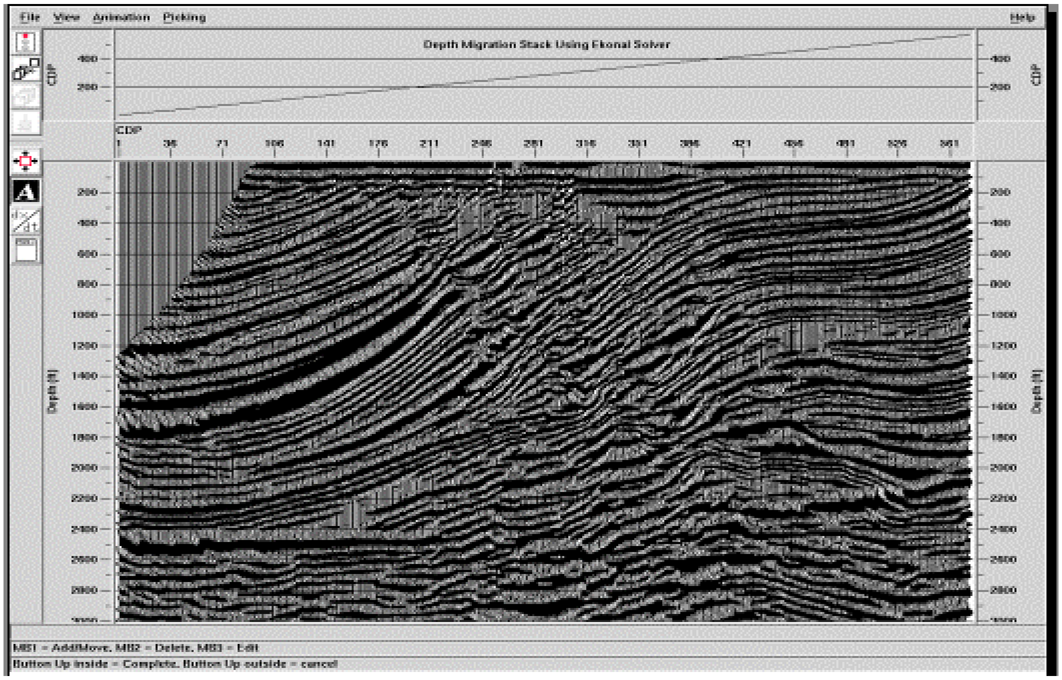

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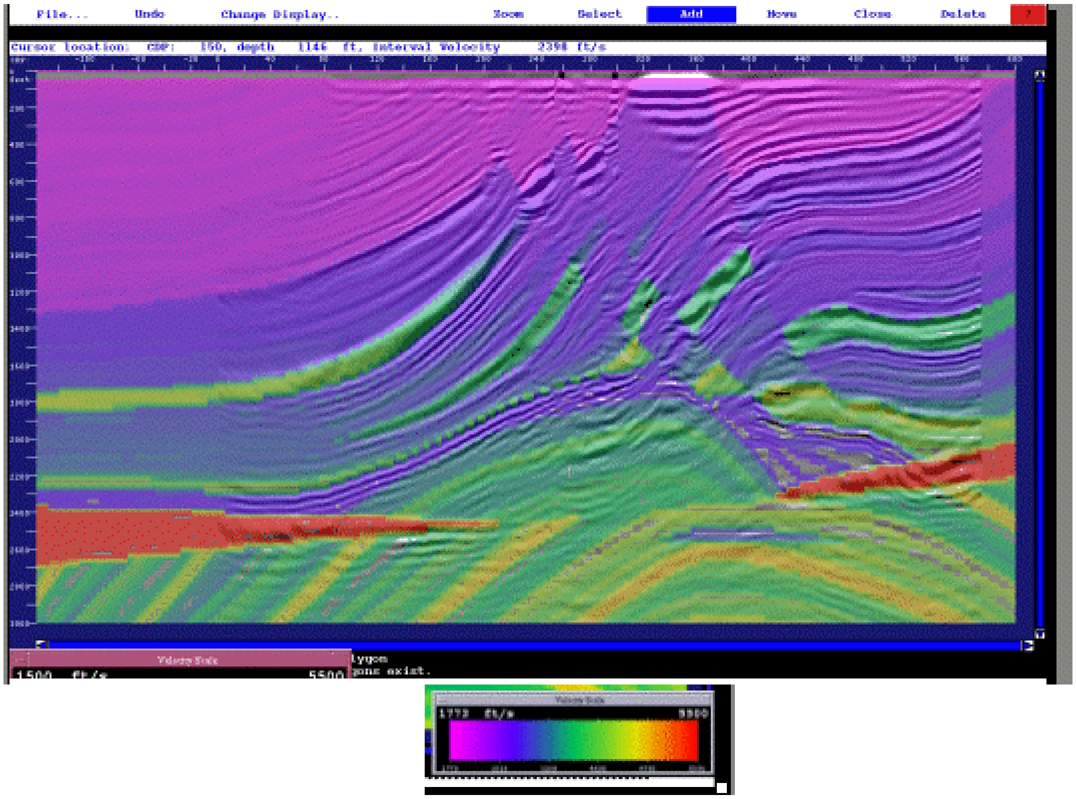
Figure 4.4 Depth migrated stack



Cursor location: CDP: 150, depth 1146 ft, interval Velocity 2398 ft/s

lygon

gons exist.

Figure 4.5 Depth migrated stack with the velocity as a template

A detailed analysis of the results of the migration stack section showed that the upper 2-km is well imaged because the first arrival travel times accurately parameterize the high energy portion of the wave field. The left and right sides of the section are well imaged because the velocity model is relatively simple. However, the central portion is complicated by the overlying faults, and the fast salt velocity produced a poor image at the target anticline (2500 meters). This poor image as a result of the break down of the calculation of the first arrival travel times is what we address with our work.

4.3 Pre-stack wave equation datuming

Prestack wave equation datuming performs datuming on unstacked data using explicit finite difference extrapolators. This process performs datuming on either shots or receivers. If the input is shot ordered, receivers will be datumed. If the input is receiver ordered, shots will be datumed. To completely perform prestack datuming, application to both shots and receivers is required (see appendix for the processing flow). The velocity is entered in an interval velocity versus depth table, and referenced to the final datum.

Synthetic exercise:

Before we ran the prestack wave equation redatum on the Marmousi data, the idea of running this process through a simple synthetic dataset came up, so we would have a better understanding of the process without the complexity of the actual Marmousi seismic data. In order to do that, on ProMAX we used a program called *synthetic for linear v (x,z).* Synthetic for linear v (x,z) generates a synthetic P-wave seismogram for specified reflectors embedded in a subsurface for which velocity varies linearly. This tool reads traces and replaces them with synthetic traces. All trace headers and geometry were copied into the synthetic trace headers. Two reflectors were generated at time 2.0 and 2.5 seconds as input. Figure (4.6) shows the synthetic data.

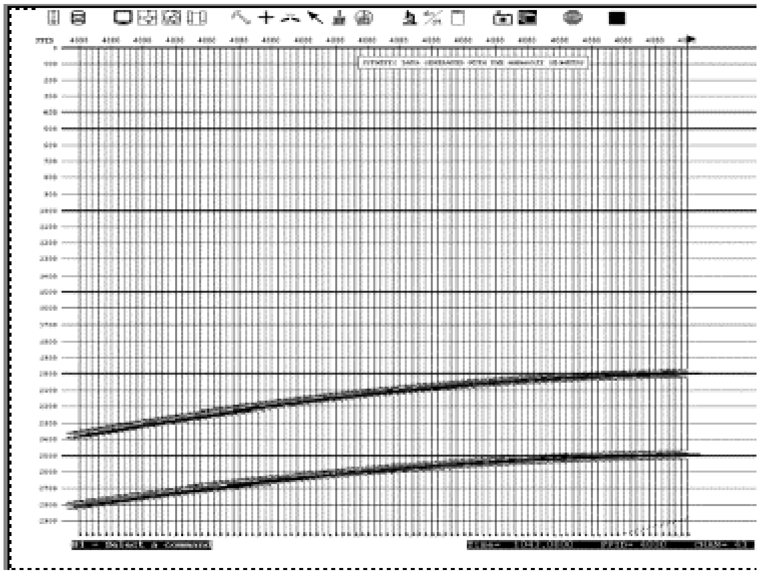


Figure 4.6 Synthetic data

A flow was set up to datum the receivers by reading the data in shot order. The datuming was done with a constant velocity of 2000 m. /sec and the elevation to datumize to was –1000 meters. Figure (4.7) shows the synthetic data after receiver redatum. The data after the receiver redatum was the input to the source redatum. The source redatum was done with the same constant velocity 2000m/sec and datumized to elevation of –1000 meters. Figure (4.8) shows the data after source redatum.

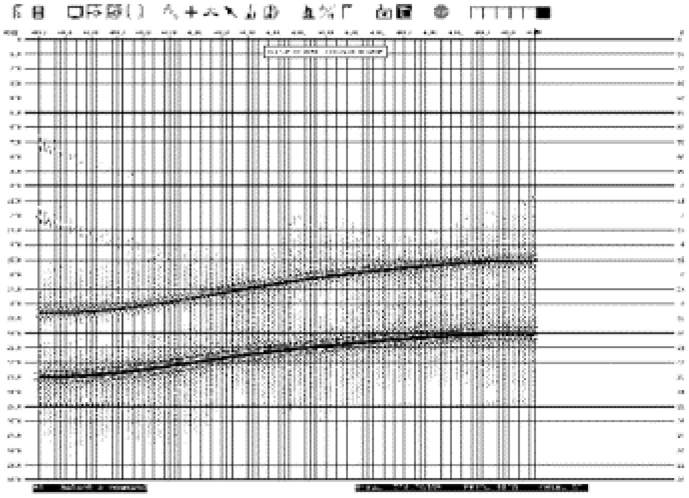


Figure 4.7 Synthetic data after redatum of the receivers

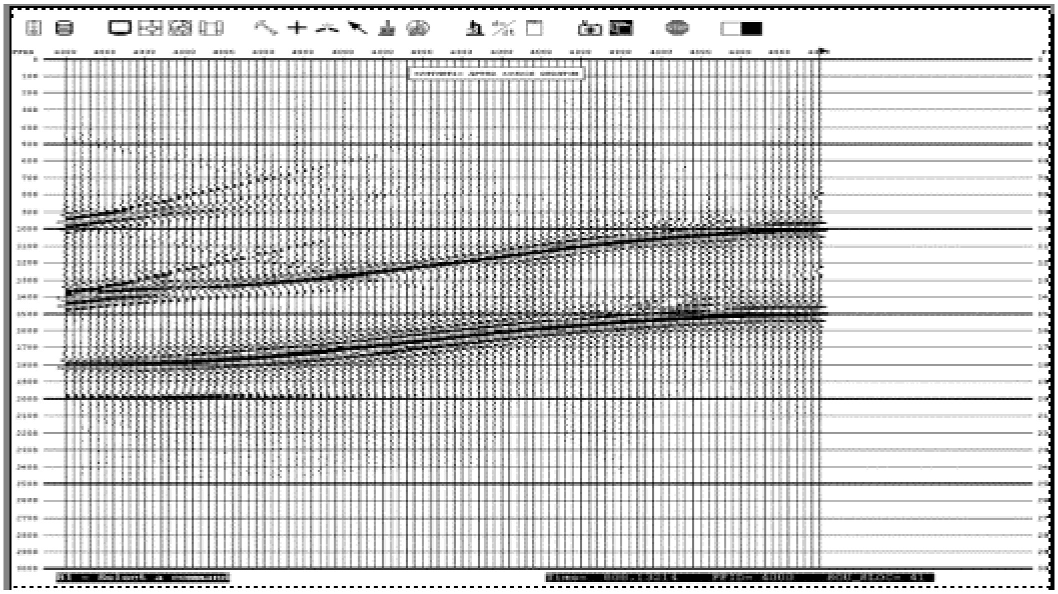


Figure 4.8 Synthetic data after redatum of the source

Two observations must be mentioned after this exercise:

- After each redatum step the data was shifted up by –0.5 seconds, and that is correct given that we are using a constant velocity of 2000 meters/second and datumizing to an elevation of –1000.
- There is a linear noise train generated because of the redatum process at the edges. We did eliminate this noise by padding traces on the edges as well applying top and bottom clean-up mutes before the redatum.

The data after both redatum steps was migrated using prestack Kirchhoff migration. Common image (CIG) gathers were generated then stacked. Figure (4.9) shows migrated CIG gathers and Figure (4.10) shows a stack of the synthetic CIG gathers.

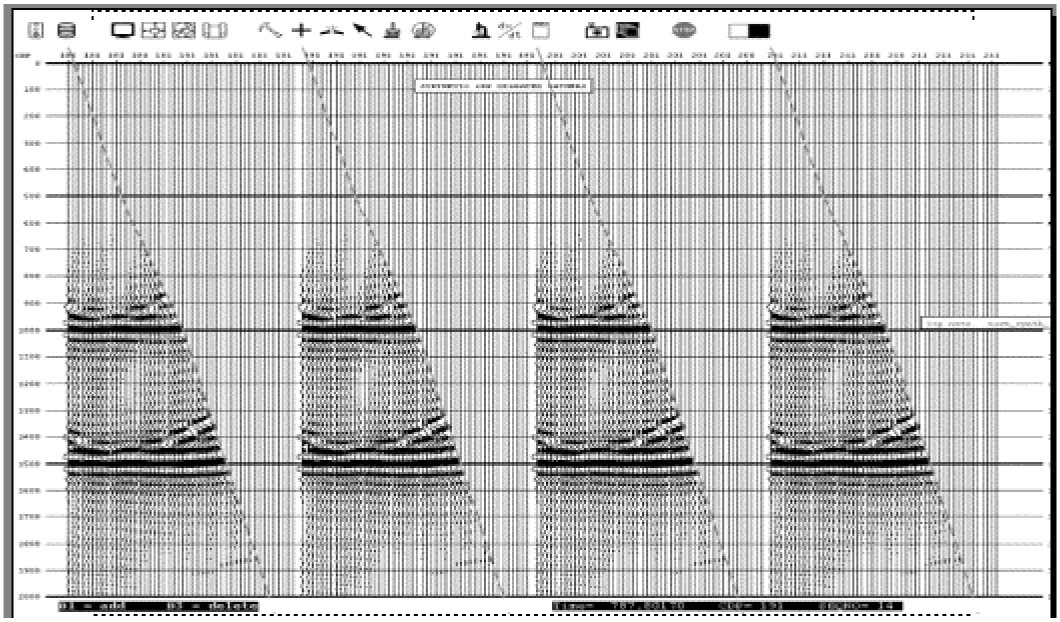


Figure 4.9 Depth migrated gathers of the synthetic data

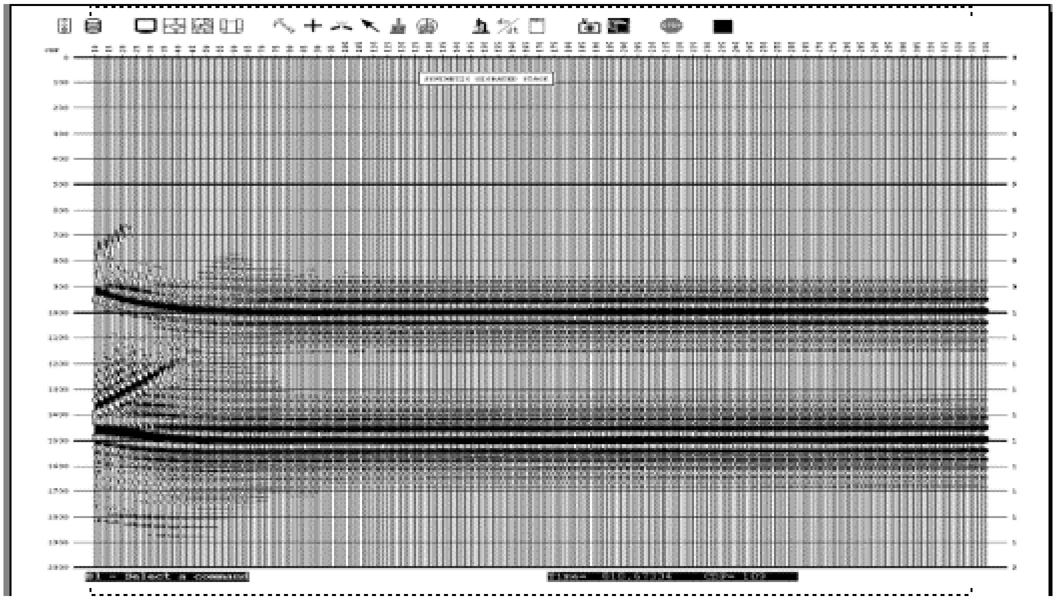


Figure 4.10 Depth migrated stack of the synthetic data

The exercise was a good test for the programs and the flows we will be using with the Marmosui data. The noise generated by the datuming process needs to be addressed before datuming the Marmousi data. The next paragraph explains how we take care of the noise problem.

Marmousi data:

After we finished the synthetic exercise, we performed the same exercise on the Marmousi data. We started with the original data; Figure (4.1) shows FFID 4000 from the original data. This data was the input to the first step, which was the redatum of the receiver to an elevation of –1000 meters. The velocity we used for the redatum was the Marmousi velocity model. Figure (4.2) shows the velocity model. A similar flow to the receiver redatum of the synthetic data was set up for the receiver redatum of the Marmousi data. Figure (4.11) shows the same FFID 4000 after the receiver redatum. Clearly we do not have the noise we saw in the synthetic data due to trace padding (20 traces) we add to the gathers and the clean-up mute we applied. The same exercise was applied to the source redatum. Figure (4.12) shows the same FFID 4000 after the source redatum. Common offsets were checked given that we would next run the migration in the common offset domain. Figure (4.13) shows offsets 250 and 450 from the redatum data. Looking at offset 450 we can see the data at the target zone is free of noise and that will help the migration process to image at that depth.

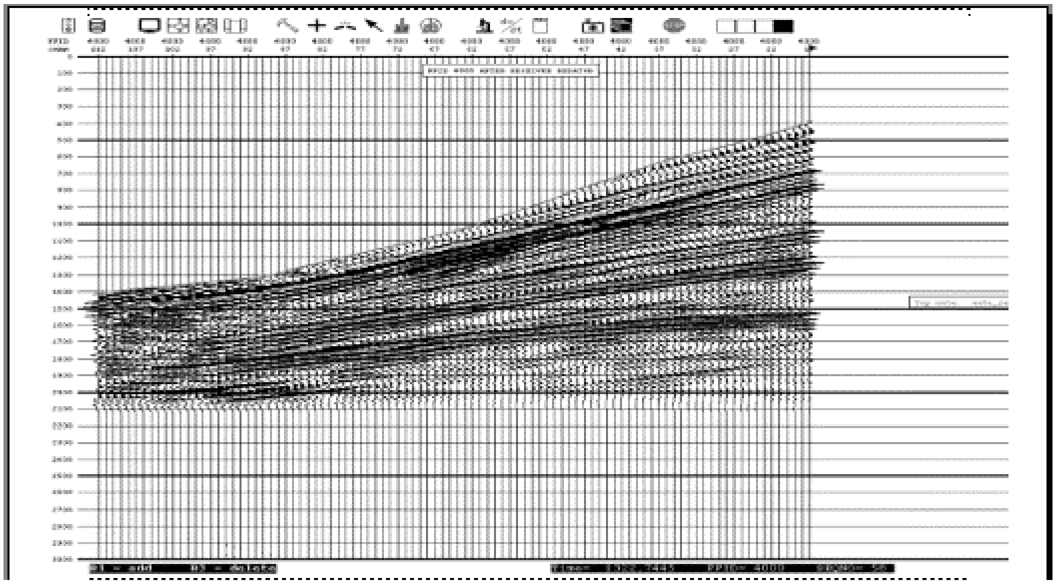


Figure 4.11 FFID 4000 after redatum of the receivers

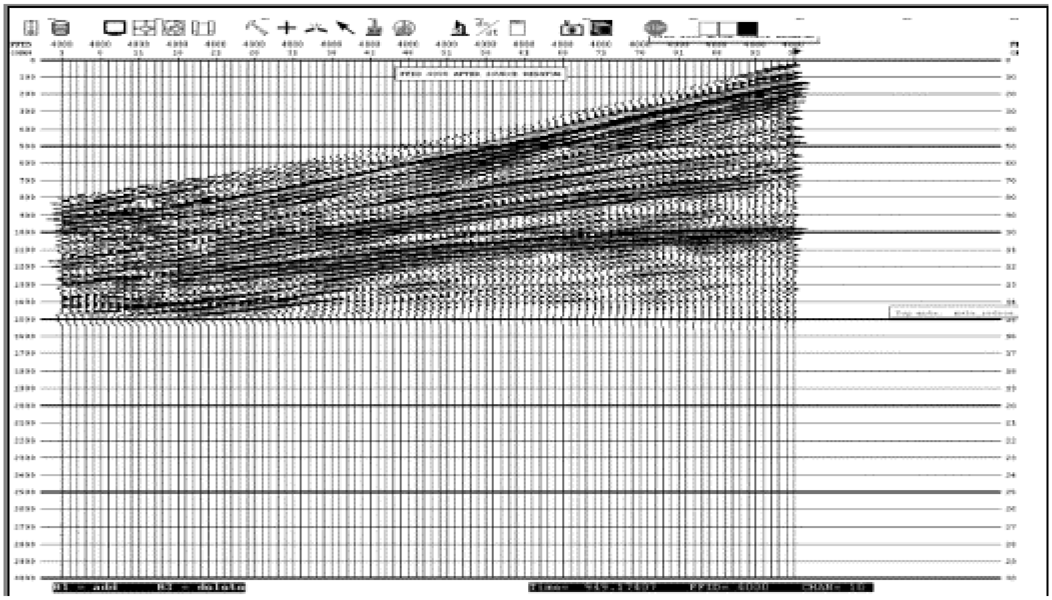


Figure 4.12 FFID 4000 after redatum of the source

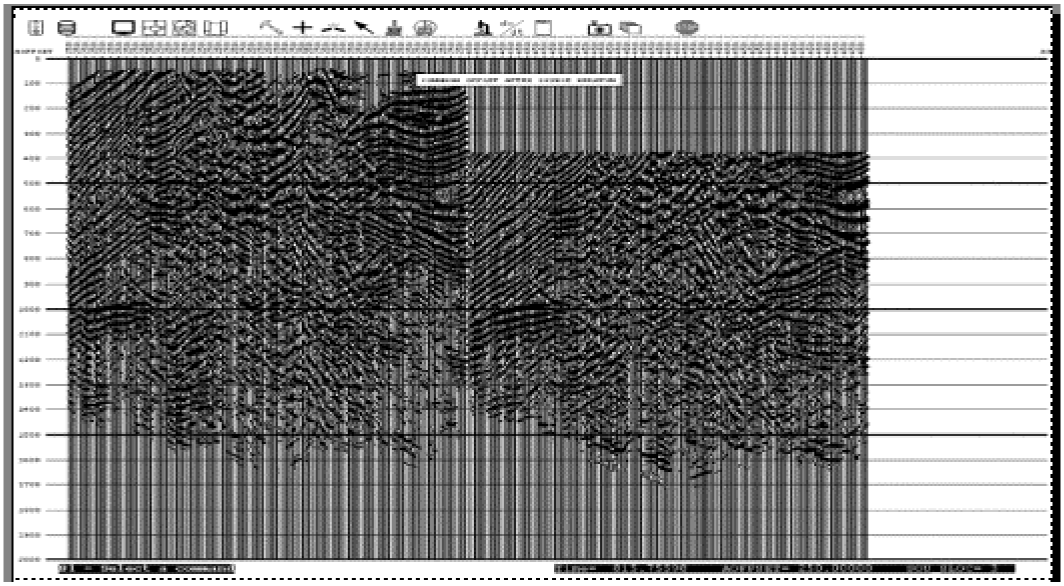
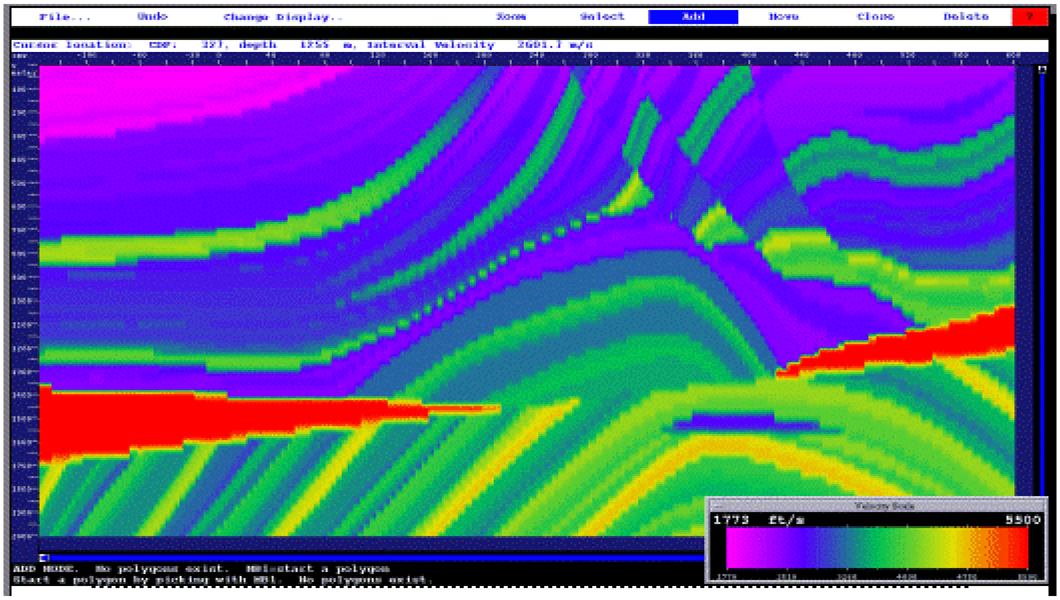


Figure 4.13 Common offsets 250&450 from the redatum data

Velocity Model:

After much testing of the migration algorithm we found that we could not use the original velocity model for the migration of the redatumed data. A module on ProMAX called “Velocity manipulation” allowed us to redatum a velocity model to a user-defined elevation (see appendix for the processing flow). Figure (4.14) shows the velocity model after the redatum to elevation of -1000 meters.



Cursor location: CDP: 327, depth 1755 m, interval Velocity 2601.7 m/s

ADD MODE. No polygons exist. MB1=start a polygon
Start a polygon by picking with MB1. No polygons exist.

Figure 4.14 Marmousi velocity model redatumed to –1000 meters

By accomplishing the datuming of the velocity and the seismic data, we are ready to take this data and migrate it and compare the results to the standard Kirchhoff migration we achieved in chapter 4.2.

4.4 Pre-stack Kirchhoff migration of the redatumed Marmousi data

The common offsets from the redatumed data were the input to the Kirchhoff depth migration algorithm. A flow was set up to perform the migration (see appendix for the processing flow). In this migration we have truncated trace length to clean the bottom part of the data from the wrap around data from the redatum process. A top mute was applied pre-migration for clean up of the data prior to the migration.

Looking at some of the common offsets after the migration we noticed that the target zone is much better imaged than before, especially the anticline beneath the salt and the salt bodies. Figure (4.15) and (4.16) show offsets 250 and 450 after the migration.

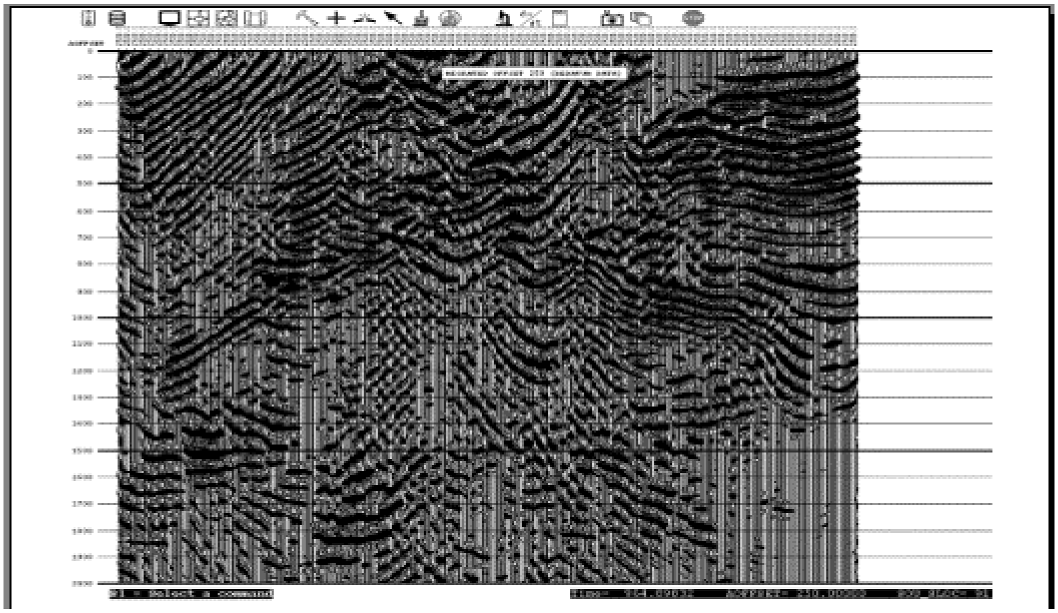


Figure 4.15 Common offset 250 after Kirchhoff depth migration

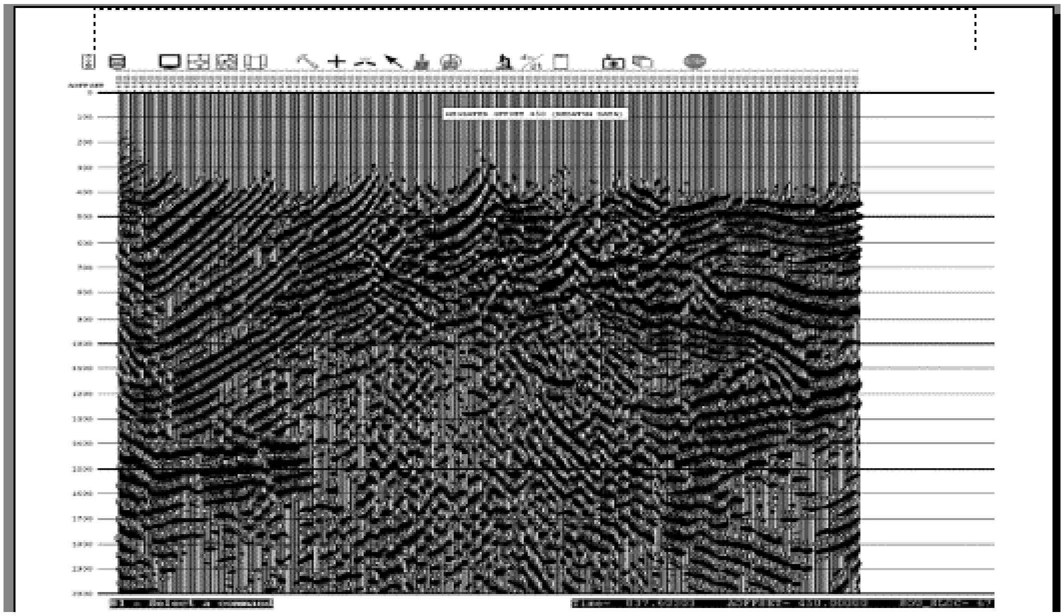


Figure 4.16 Common offset 450 after Kirchhoff depth migration

Figure (4.17) shows full offsets migrated CIG’s. The data around 1500 meters is much better imaged if we compare those gathers to the same gathers before the redatum at 2500 meters. The gathers then were stacked; Figure (4.18) shows the stack of the redatumed data from 0 to 2 KM which correspond to 1 to 3 KM in the original migrated section. Clearly we can see we have a much better focused image at depths between 2.2 to 3.0 km, especially at the target anticline as well the beds on both sides of the model. The stack section is displayed as a template with the redatum velocity Figure (4.19).

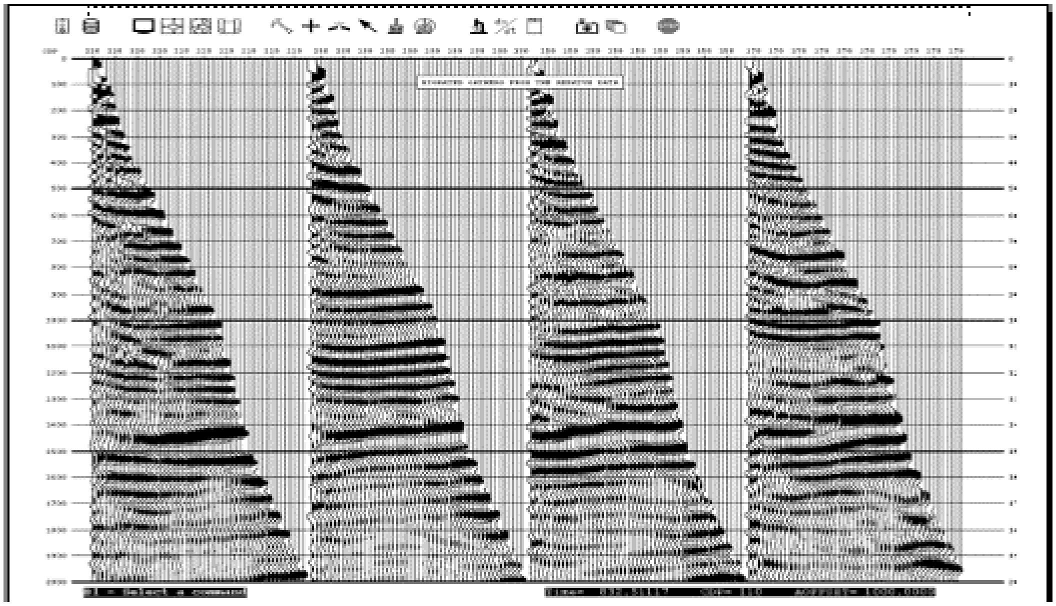


Figure 4.17 Depth migrated gathers after redatum

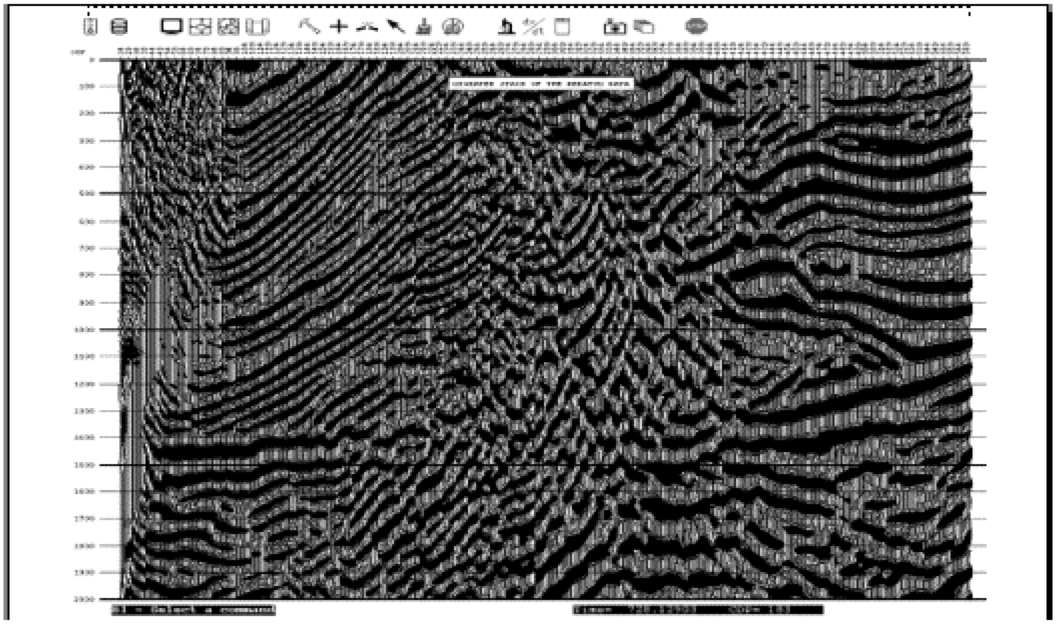
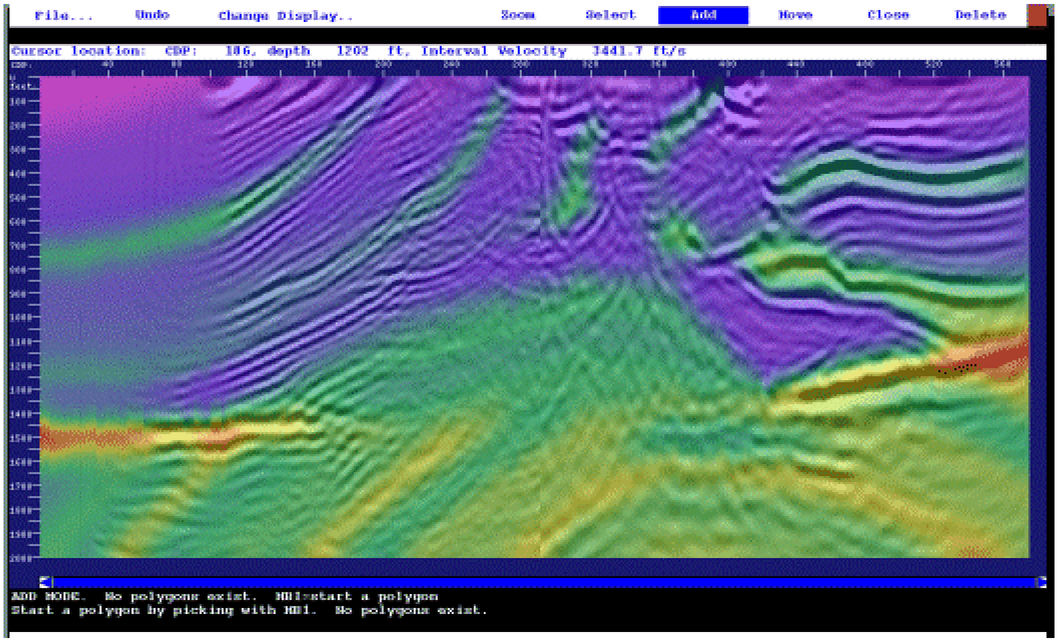


Figure 4.18 Depth migrated stack after redatum



```
Cursor location:  CDP:   186, depth   1202  ft, Interval Velocity   3441.7 ft/s
```

```
ADD MODE.  No polygons exist.  MB1=start a polygon
Start a polygon by picking with MB1.  No polygons exist.
```

Figure 4.19 Depth migrated stack after redatum with the velocity model as a template

If we compare the stack section of the redatum data to the same section we had before the redatum we can not miss the improvement we have achieved in the bottom 1 km of the section, especially at the target anticline as well as the salt bodies. And this is the upshot of the exercise: by applying the wave equation datuming to the data we basically lowered the source and receivers to a new datum, thereby ensuring that the first-arrival travel times are a better approximation to the most energetic arrivals. Then by performing Kirchhoff migration from the new datum we achieved a much better focused image compared to the same image we had before the redatum process.

Chapter 5

Discussion and Future Work

Discussion:

The work we have done showed that we can get a better focused image, especially if we are trying to image a complex structure, by using the semi-recursive migration method. However, this method has benefits beyond that:

- After the redatum process, the traces get shorter; hence, computation and storage requirements are reduced.
- After each redatum the aperture for the migration and the redatum can be reduced. This will not only reduce the number of calculations, but also the amount of the input data kept in memory for any given output location.
- By doing this exercise using a widely used processing package (ProMAX), we showed that we could apply this method with software that already exists. That is in itself an advantage we should explore in other data sets which may benefit from this technique.
- In the data examples presented, we redatumed the data to a flat surface. At this point we do not see a reason not to redatum the data to an arbitrary surface such as the water bottom in case of deep-water exploration. This point is very important given the potential worldwide for deepwater exploration. With deep-water data from West

Africa, Brazil and Gulf of Mexico, the semi-recursive migration is a technique that should be evaluated to get a better-focused image in such areas.

Future work:

From the experience we built through carrying out this exercise, we believe that the future for this work definitely is in the 3-D domain. The advantages we get from the 3-D approach are huge, especially where detailed imaging is required. However, this comes with a price of a huge amount of data to handle. The challenges we will face when extending this exercise to 3-D would be:

- How fast we can get the wave equation datuming done on a huge amount of data.
- How the wave equation datuming will handle the irregular sampling that we have with 3-D on both land and marine data.

Another area to see if this method is applicable is deepwater data. This method should be the way to go. The data from such areas should benefit from this method in the following ways:

- Better focused images at greater depth.
- Better handle on fixing problems in deepwater exploration such as velocity error and static shift because of a change in water temperatures or change in acoustic impedance (because of the existence of fresh water near rivers, for instance). The velocity error or static shift causes distortion of the image.

- Cost is always an issue; this method should save money and effort. One example of saving money is by shortening the trace length by taking out the length of the water column which in some cases is up to 50% of the trace length, thereby saving in the amount of computation and storage spaces (which is an issue in case of 3-D). By getting a good image we most likely avoid reprocessing of the data and that is indeed saves effort.

Chapter 6

Conclusion

By combining prestack wave equation datuming and prestack Kirchhoff migration, we achieved a much better focused image compared to the standard Kirchhoff migration. We have done this by using a method called semi-recursive Kirchhoff migration. This method is based on wave equation datuming of the seismic data and subdivisions of the velocity model where the travel time calculation with finite differencing the eikonal equation is valid. By dividing the velocity model, the number of travel times that need to be calculated is dramatically reduced, and hence storage space is significantly reduced. The key point in the calculation of the travel time is that the travel times should correspond to the most energetic arrivals and consequently end up with a good image. Areas will benefit the most from this method where we have complex geologic structures with deep targets and complex velocity models with rapid lateral velocity variations.

While performing the semi-recursive migration method, we did not use proprietary codes, which are generally not available, but instead we used a widely used processing package with its existing software. That in itself is a big advantage because we think there are lots of seismic data which will benefit from this method, but nobody knows that this technique is available and ready to use. In the example we showed, we downward continued the data to a flat surface, but there is no reason not to use an arbitrary surface such as the water bottom in the case of marine deep water.

Using the finite difference method to compute travel times is not a limit to the semi-recursive migration; we can use any other method as long the calculation of the travel times is accurate. The better the travel times calculated, the better the final image. However, intensive computation of the travel time is not needed with the semi-recursive method, and that is one of the efficient and cost effective factors we can accomplish with this method without affecting the final image. Moreover, we showed with the Marmousi data examples that we can accomplish a better image.

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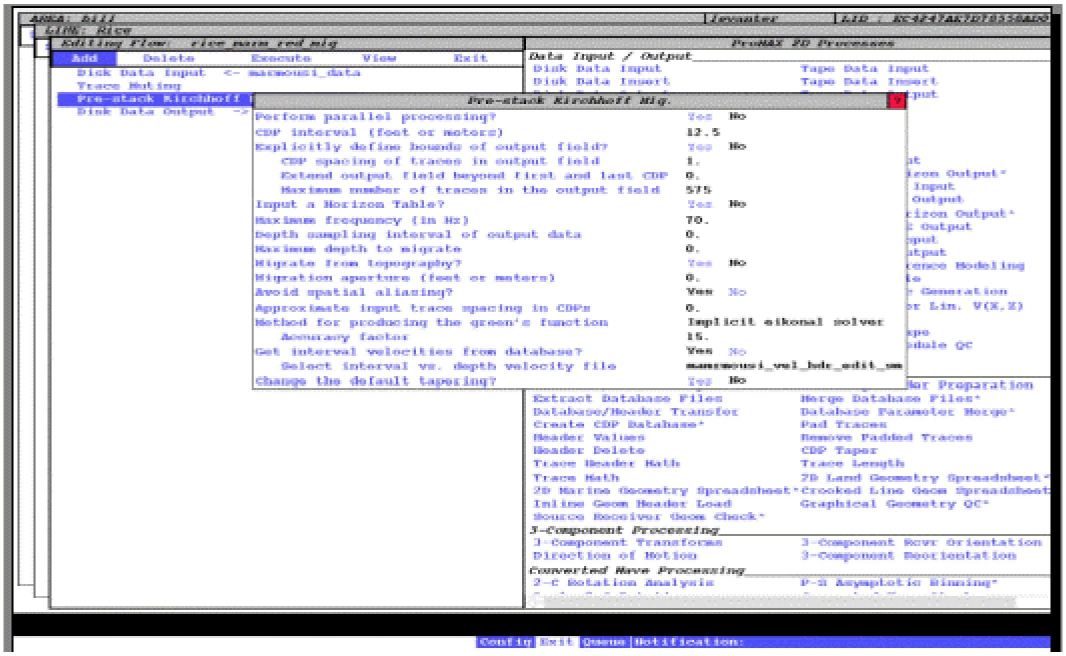
Appendix

ProMAX's Processing Flows

In this appendix we will have all the flows that we set up on ProMAX to perform the following process:

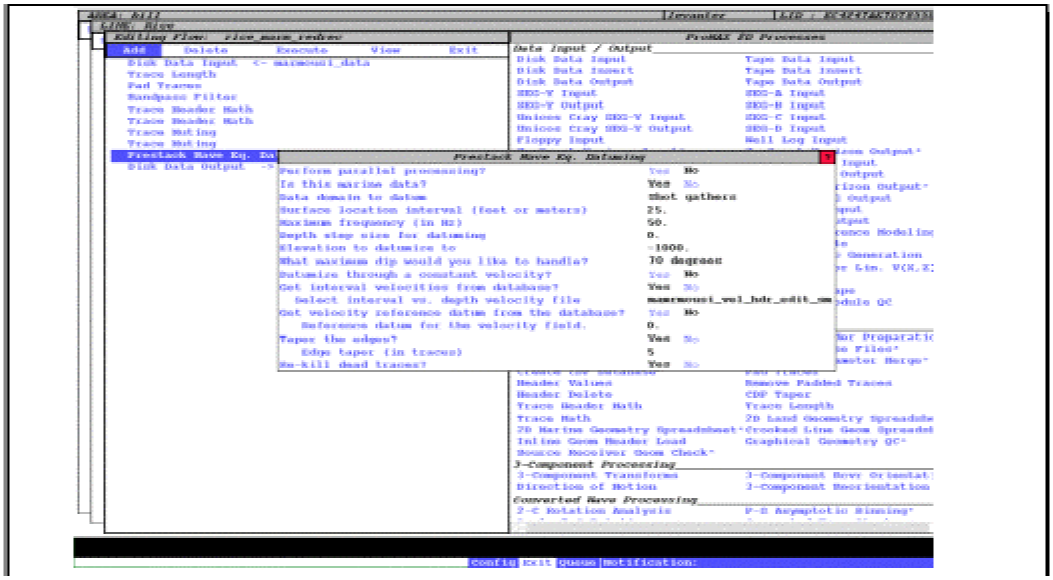
- Standard Kirchhoff migratin
- Wave equation datuming of the synthetic data
- Wave equation datuming of the Marmousi data
- Redatum the Velocity model
- Kirchhoff migration of the redatum data



```
Disk Data Input  <- marmousi_data
Trace Muting
Pre-stack Kirchhoff Mig.
Disk Data Output ->

Pre-stack Kirchhoff Mig.
Perform parallel processing?                        Yes  No
CDP interval (feet or meters)                       12.5
Explicitly define bounds of output field?           Yes  No
   CDP spacing of traces in output field            1.
   Extend output field beyond first and last CDP    0.
   Maximum number of traces in the output field     575
Input a Horizon Table?                              Yes  No
Maximum frequency (in Hz)                           70.
Depth sampling interval of output data              0.
Maximum depth to migrate                            0.
Migrate from topography?                            Yes  No
Migration aperture (feet or meters)                 0.
Avoid spatial aliasing?                             Yes  No
Approximate input trace spacing in CDPs             0.
Method for producing the green's function           Implicit eikonal solver
   Accuracy factor                                  15.
Get interval velocities from database?              Yes  No
   Select interval vs. depth velocity file          marmousi_vel_hdr_edit_sm
Change the default tapering?                        Yes  No
```

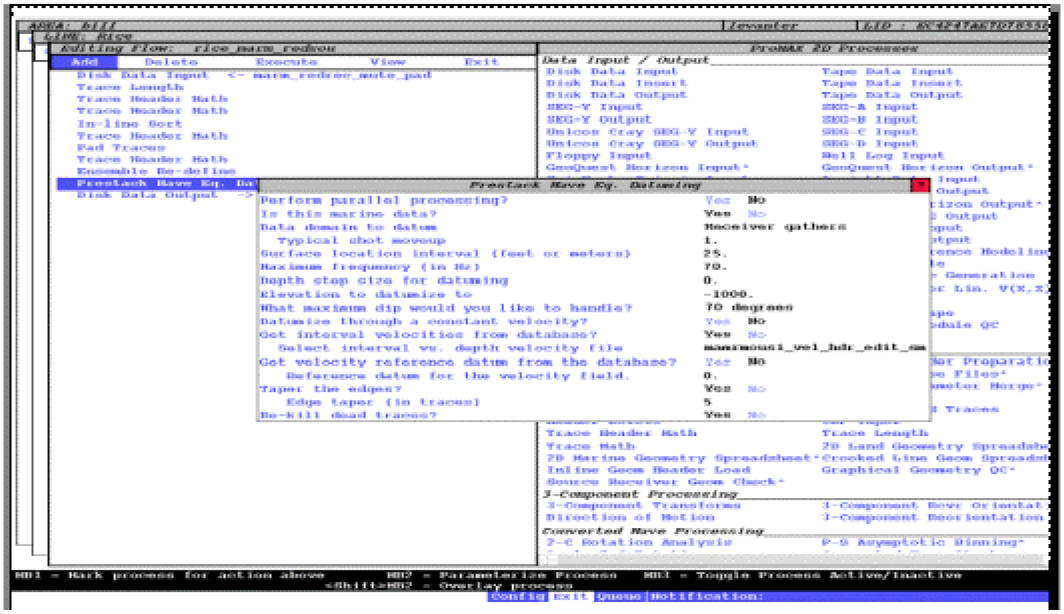
ProMAX flow to run Standard Kirchhoff migration



Prestack Wave Eq. Datuming

Perform parallel processing? No
Is this marine data? Yes
Data domain to datum: Shot gathers
Surface location interval (feet or meters): 25.
Maximum frequency (in Hz): 50.
Depth step size for datuming: 0.
Elevation to datumize to: -1000.
What maximum dip would you like to handle? 70 degrees
Datumize through a constant velocity? No
Get interval velocities from database? Yes
Select interval vs. depth velocity file: marmousi_vel_hdr_edit_sm
Get velocity reference datum from the database? No
Reference datum for the velocity field. 0.
Taper the edges? Yes
Edge taper (in traces): 5
Re-kill dead traces? Yes

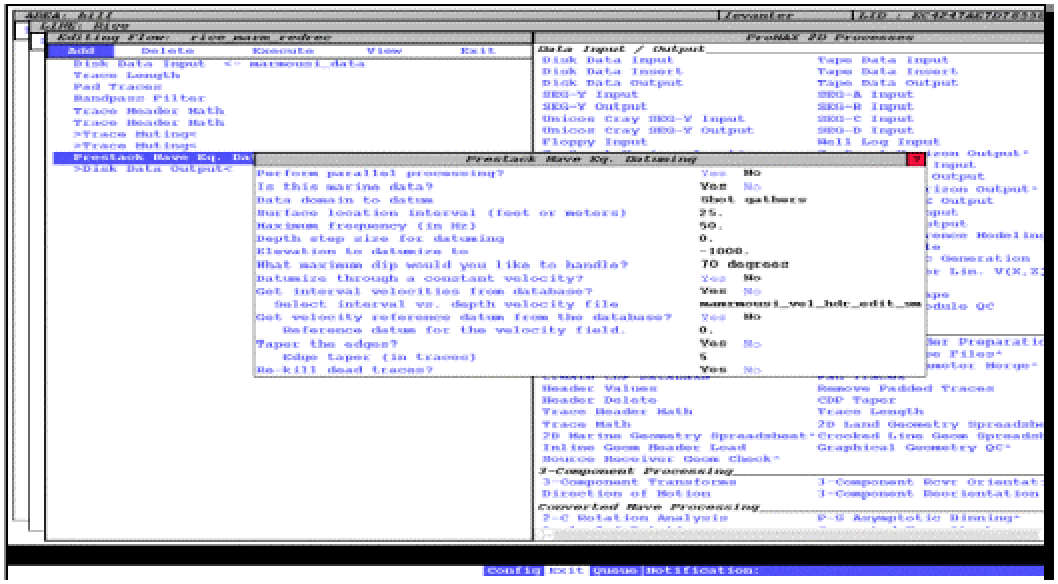
ProMAX flow to redatum the receivers of the synthetic data



Prestack Wave Eq. Datuming

Perform parallel processing? No
Is this marine data? Yes
Data domain to datum: Receiver gathers
Typical shot moveup: 1.
Surface location interval (feet or meters): 25.
Maximum frequency (in Hz): 70.
Depth step size for datuming: 0.
Elevation to datumize to: -1000.
What maximum dip would you like to handle? 70 degrees
Datumize through a constant velocity? No
Get interval velocities from database? Yes
Select interval vs. depth velocity file: marmousi_vel_hdr_edit_sm
Get velocity reference datum from the database? No
Reference datum for the velocity field. 0.
Taper the edges? Yes
Edge taper (in traces): 5
Re-kill dead traces? Yes

ProMAX flow to redatum the source of the synthetic data



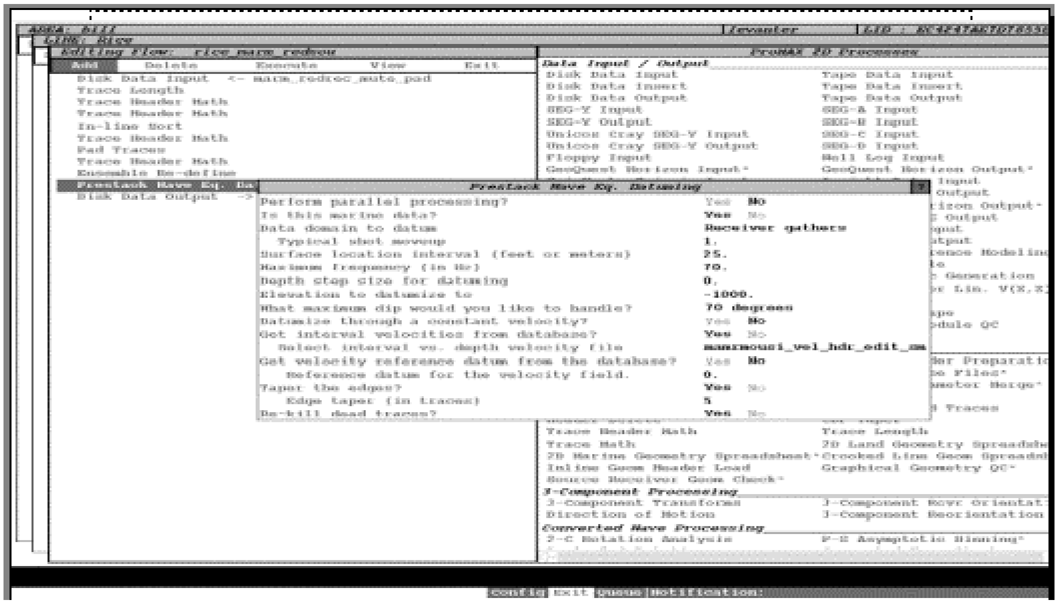
Editing Flow: rice_marm_redrec

- Disk Data Input <- marmousi_data
- Trace Length
- Pad Traces
- Bandpass Filter
- Trace Header Math
- Trace Header Math
- >Trace Muting<
- >Trace Muting<
- Prestack Wave Eq. Da
- >Disk Data Output<

Prestack Wave Eq. Datuming

Perform parallel processing? Yes [✓ No]
Is this marine data? [✓ Yes] No
Data domain to datum: Shot gathers
Surface location interval (feet or meters): 25.
Maximum frequency (in Hz): 50.
Depth step size for datuming: 0.
Elevation to datumize to: -1000.
What maximum dip would you like to handle? 70 degrees
Datumize through a constant velocity? Yes [✓ No]
Get interval velocities from database? [✓ Yes] No
Select interval vs. depth velocity file: marmousi_vel_hdr_edit_sm
Get velocity reference datum from the database? Yes [✓ No]
Reference datum for the velocity field. 0.
Taper the edges? [✓ Yes] No
Edge taper (in traces): 5
Re-kill dead traces? [✓ Yes] No

ProMAX flow to redatum the receivers of the Marmousi data



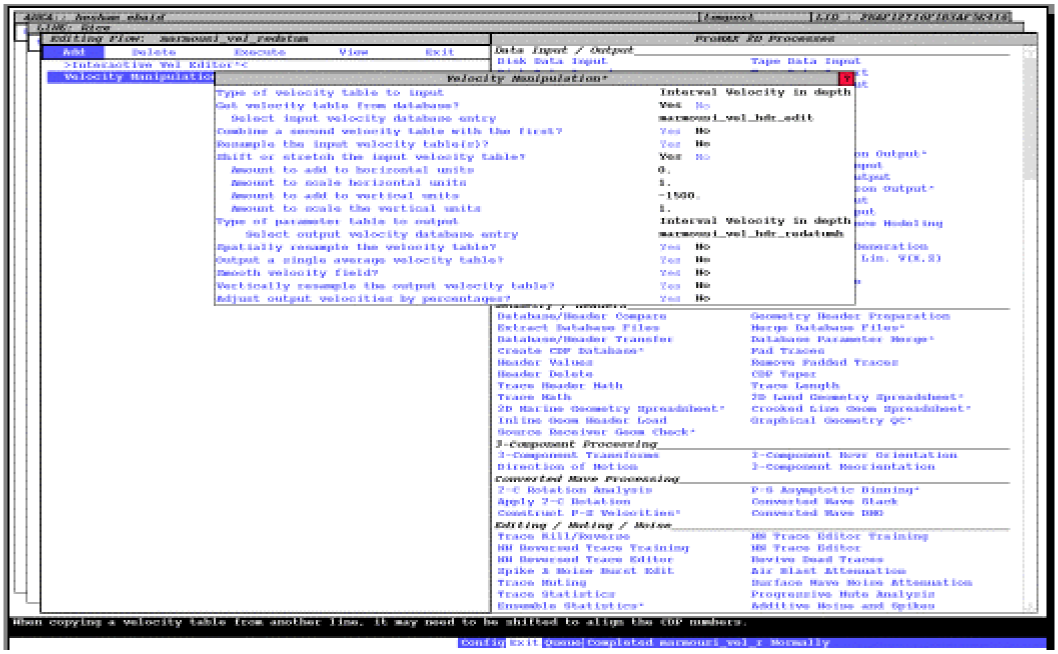
Editing Flow: rice_marm_redsou

- Disk Data Input <- marm_redrec_mute_pad
- Trace Length
- Trace Header Math
- Trace Header Math
- In-line Sort
- Trace Header Math
- Pad Traces
- Trace Header Math
- Ensemble Re-define
- Prestack Wave Eq. Da
- Disk Data Output ->

Prestack Wave Eq. Datuming

Perform parallel processing? Yes [✓ No]
Is this marine data? [✓ Yes] No
Data domain to datum: Receiver gathers
Typical shot moveup: 1.
Surface location interval (feet or meters): 25.
Maximum frequency (in Hz): 70.
Depth step size for datuming: 0.
Elevation to datumize to: -1000.
What maximum dip would you like to handle? 70 degrees
Datumize through a constant velocity? Yes [✓ No]
Get interval velocities from database? [✓ Yes] No
Select interval vs. depth velocity file: marmousi_vel_hdr_edit_sm
Get velocity reference datum from the database? Yes [✓ No]
Reference datum for the velocity field. 0.
Taper the edges? [✓ Yes] No
Edge taper (in traces): 5
Re-kill dead traces? [✓ Yes] No

ProMAX flow to redatum the source of the Marmousi data



Editing Flow: marmousi_vel_redatum

>Interactive Vel Editor<
Velocity Manipulation

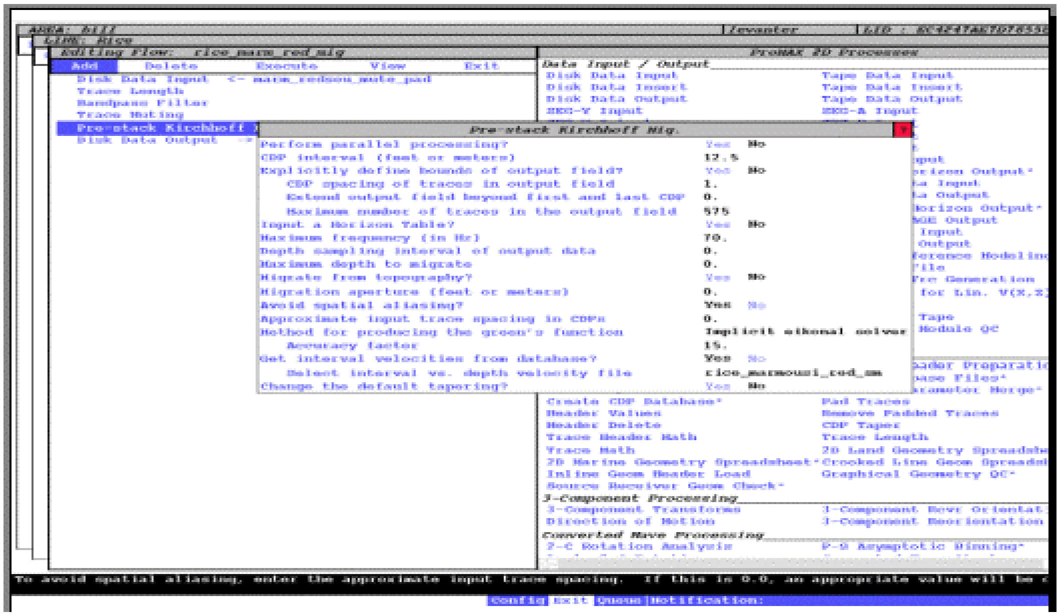
Velocity Manipulation*

Type of velocity table to input	Interval Velocity in depth
Get velocity table from database?	Yes
Select input velocity database entry	marmousi_vel_hdr_edit
Combine a second velocity table with the first?	No
Resample the input velocity table(s)?	No
Shift or stretch the input velocity table?	Yes
Amount to add to horizontal units	0.
Amount to scale horizontal units	1.
Amount to add to vertical units	-1500.
Amount to scale the vertical units	1.
Type of parameter table to output	Interval Velocity in depth
Select output velocity database entry	marmousi_vel_hdr_redatumh
Spatially resample the velocity table?	No
Output a single average velocity table?	No
Smooth velocity field?	No
Vertically resample the output velocity table?	No
Adjust output velocities by percentages?	No

When copying a velocity table from another line, it may need to be shifted to align the CDP numbers.

Completed marmousi_vel_r Normally

ProMAX flow to redatum the Marmousi velocity model



Editing Flow: rice_marm_red_mig

Disk Data Input <- marm_redsou_mute_pad
Trace Length
Bandpass Filter
Trace Muting
Pre-stack Kirchhoff Mig.
Disk Data Output

Pre-stack Kirchhoff Mig.

Perform parallel processing?	No
CDP interval (feet or meters)	12.5
Explicitly define bounds of output field?	No
CDP spacing of traces in output field	1.
Extend output field beyond first and last CDP	0.
Maximum number of traces in the output field	575
Input a Horizon Table?	No
Maximum frequency (in Hz)	70.
Depth sampling interval of output data	0.
Maximum depth to migrate	0.
Migrate from topography?	No
Migration aperture (feet or meters)	0.
Avoid spatial aliasing?	Yes
Approximate input trace spacing in CDPs	0.
Method for producing the green's function	Implicit eikonal solver
Accuracy factor	15.
Get interval velocities from database?	Yes
Select interval vs. depth velocity file	rice_marmousi_red_sm
Change the default tapering?	No

To avoid spatial aliasing, enter the approximate input trace spacing. If this is 0.0, an appropriate value will be c

ProMAX flow to migrate the redatum Marmousi data